

CASE REPORT

RETURN TO RUNNING FOLLOWING A KNEE
DISARTICULATION AMPUTATION: A CASE REPORTAngela R. Diebal-Lee¹Robert S. Kuenzi²Christopher A. Rábago^{2,3}

ABSTRACT

Background and Purpose: The evolution of running-specific prostheses has empowered athletes with lower extremity amputations to run farther and faster than previously thought possible; but running with proper mechanics is still paramount to an injury-free, active lifestyle. The purpose of this case report was to describe the successful alteration of intact limb mechanics from a Rearfoot Striking (RFS) to a Non-Rearfoot Striking (NRFS) pattern in an individual with a knee disarticulation amputation, the associated reduction in Average Vertical Loading Rate (AVLR), and the improvement in functional performance following the intervention.

Case description: A 30 year-old male with a traumatic right knee disarticulation amputation reported complaints of residual limb pain with running distances greater than 5 km, limiting his ability to train toward his goal of participating in triathlons. Qualitative assessment of his running mechanics revealed a RFS pattern with his intact limb and a NRFS pattern with his prosthetic limb. A full body kinematic and kinetic running analysis using 3D motion capture and force plates was performed. The average intact limb loading rate was four-times greater (112 body weights/s) than in his prosthetic limb which predisposed him to possible injury. He underwent a three week running intervention with a certified running specialist to learn a NRFS pattern with his intact limb.

Outcomes: Immediately following the running intervention, he was able to run distances of over 10 km without pain. On a two-mile fitness test, he decreased his run time from 19:54 min to 15:14 min. Additionally, the intact limb loading rate was dramatically reduced to 27 body weights/s, nearly identical to the prosthetic limb (24 body weights/s).

Discussion: This case report outlines a detailed return to run program that targets proprioceptive and neuromuscular components, injury prevention, and specificity of training strategies. The outcomes of this case report are promising as they may spur additional research toward understanding how to eliminate potential injury risk factors associated with running after limb loss.

Keywords: Amputation, running, limb loading rate

Level of Evidence: 4

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BACKGROUND

A common goal following a lower extremity amputation is for the individual to return to their pre-injury lifestyle. For those with active lifestyles and occupations, running can be central to achieving these endeavors. The development and evolution of running-specific prostheses has empowered recreational runners¹ and Paralympic athletes to run farther and faster than previously thought possible.²⁻⁴ Despite the advancement of running prostheses,^{5,6} proper and symmetric mechanics are paramount to successful running and injury avoidance.⁷⁻⁹ Differing foot strike patterns between the prosthetic and intact limb is a common problem for individuals with unilateral lower extremity amputation, making a return to injury-free running challenging. Contemporary energy-storing-and-returning prosthetic limbs are optimized for running and require the runner to strike the ground in using a non-rear foot striking (NRFS) pattern. However, approximately 80% of runners use a rear foot striking (RFS) pattern;^{10,11} thus, an individual following a unilateral lower extremity amputation may attempt to run with asymmetric foot striking patterns.

In able-bodied individuals, running with a RFS as opposed to a NRFS pattern significantly increases average vertical ground reaction force loading rates (AVLR), maximum braking forces, negative work of the ankle dorsiflexors, and negative work of the knee extensors.^{12,13} These biomechanical characteristics are associated with increased musculoskeletal injury risk through increased tissue stresses.¹⁴⁻¹⁹ Most healthy RFS runners demonstrate AVLRs between 60-70 body weights/second (BW/s) in laboratory studies.¹⁴ AVLRs greater than 70 BW/s are associated with tibial and metatarsal stress fractures, patellofemoral pain syndrome, and plantar fasciitis.^{9,11,20} Typical AVLRs for NRFS runners are observed from 40-60 BW/s; lower than the reported values that place people at risk for many common running injuries.^{11,12}

An individual with a unilateral lower extremity amputation may be at similar risk for injuries if using a RFS pattern on their intact limb. In a case report of a 27 year-old (yo) with a unilateral transtibial amputation, average AVLR in the intact limb was 74 BW/s when using a RFS pattern.²¹ Based on the

abled-bodied literature, this high AVLR may predispose these runners to micro-traumas, stress injuries, or osteoarthritis in the intact limb.^{8,19} Further, the use of different foot strike patterns between prosthetic and intact limbs may lead to musculoskeletal imbalances and the development of secondary overuse injuries.¹⁹ In order to lessen these risks, rehabilitation programs should include instruction to foster foot strike symmetry between the prosthetic and intact limbs. Since the prosthetic limb cannot be changed to a RFS pattern, individuals must learn to produce a NRFS pattern with the intact limb.

In the case report of the 27 yo with a unilateral transtibial amputation, the clinical investigators observed a 90% reduction of average AVLR to 39 BW/s in the intact limb when using a NRFS running pattern.²¹ These investigators attributed this change to NRFS running instruction and training during rehabilitation. While these results are promising, there is no evidence to support whether a change to a NRFS running pattern in more proximal amputees would elicit similar positive results.

The purpose of this case report was to describe the successful alteration of intact limb mechanics from a RFS to a NRFS pattern in an individual with a knee disarticulation amputation, the associated reduction in AVLR, and the improvement in functional performance following the intervention.

CASE DESCRIPTION

The service member (SM) was a 30 yo male who sustained a traumatic right knee disarticulation amputation after being hit by a truck while riding his motorcycle. He also sustained a mild traumatic brain injury and multiple right metacarpal fractures that were stabilized with internal fixation hardware. He was 72 weeks post-amputation, 58 weeks post-independent ambulation, and had started running approximately 24 weeks prior to presentation. SM provided informed consent for all clinical procedures and approved the use of his data in this case report. At the time of presentation, he was discharged from rehabilitation services with all injuries well healed and no planned medical procedures. SM had a height of 1.83 m, body mass of 75.7 kg without his prosthesis, and residual limb length of 50 cm from the ipsilateral greater trochanter.

SM utilized prosthetic care services at the Center for the Intrepid, Brooke Army Medical Center (JBSA Fort Sam Houston, TX) for distribution, fitting, and maintenance of his prosthetic components. He used two separate prosthetic limbs; one for typical gait and one for running. His gait prosthesis (mass 3.2 kg) consisted of a silicone gel liner with a custom Seal-In® ring (Ossur); passive-suction, ischial-level, flexible inner socket with carbon-fiber frame including anterior and posterior fenestrations; Ossur Total Knee® 2100; and Ossur Variflex XC Rotate® energy-storing-and-returning foot. When wearing his gait prosthesis and walking shoes, SM's leg lengths were 98 cm bilaterally from ipsilateral greater trochanters to the floor. SM's running prosthesis (mass 3.2 kg) consisted of the same socket design and liner; Ottobock 3S80 Sport Knee; and Ossur Flex-Run™ foot (category 5HI). When wearing his running prosthesis and a neutral-minimalist running shoe, SM's leg lengths were 95 cm (intact limb) and 98 cm (prosthetic limb) from ipsilateral greater trochanters to the floor.

SM stated that his goals were to continue on active duty, return to his pre-injury level of fitness, and compete in triathlons. Long distance running (>5 km) was central to achieving these goals. Prior to his transfer to JBSA Fort Sam Houston, run training at a previous duty station allowed him to complete distances up to 16 km. However, he complained of bilateral lower extremity pain and residual limb swelling at distances greater than 5 km. Recovery often took several days which further limited his frequency of training reducing his running volume to less than 10 km per week. A baseline 2D running analysis was performed using the Dartfish application on an Apple iPad Air 2 by a physical therapist (ARD) with a running specialty certification. Analysis revealed an asymmetric ground-foot striking pattern; RFS with the intact limb and NRFS with the prosthetic limb.

CLINICAL IMPRESSION #1

Based on clinical indices and previous literature findings, an asymmetric ground-foot striking pattern by SM was likely contributing to his discomfort and pain when running. Further comprehensive assessment of SM's running mechanics was warranted.

EXAMINATION

A 3D biomechanical running analysis was performed at the Center for the Intrepid as SM ran at a self-selected velocity on a level 16 m runway. Motion capture collection and analysis procedures were similar to those previously reported.²¹ Full body kinematic data were collected at 120 Hz using a 26-camera infrared motion capture system (Motion Analysis Corporation, Santa Rosa, CA) to track 57 reflective markers in a modified Helen-Hayes marker set placed on hand, arm, head, trunk, pelvis, thigh, shank and foot segments. The pylon of the prosthetic limb was modeled as a shank segment and markers were attached to running foot as to follow its contour (Figure 1). Kinetic data were collected at 1200 Hz (AMTI, Inc., Watertown, MA). Temporal spatial, kinematic, and kinetic parameters were quantified using Visual 3D software (C-Motion Inc., Rockville, MD). A minimum of eight strides per limb were used in the analyses. Kinematic and kinetic data were time-normalized to 100% gait cycle. Peak values for each kinematic and kinetic parameter of interest were extracted using a custom MATLAB program (Mathworks Inc., Natick, MA). Average vertical loading rate (AVLR) was defined as the slope of the vertical ground reaction force curve between 20% and 80% of the time to first impact peak.²² AVLR was normalized to SM's body weight plus the weight his running prosthesis.

SM's average self-selected running velocity was 3.066 ± 0.048 m/s (Table 1). He spent 16.8% more time in stance on his intact limb compared to his prosthetic limb. He also spent 8.8% less time in swing with his intact limb compared to his prosthetic limb.

These temporal-spatial asymmetries corresponded to observed asymmetric ground-foot striking patterns. Sagittal ankle and knee angles of both limbs are presented in Figures 2 and 3, respectively. As typical when RFS, at initial contact; SM struck with greater dorsiflexion and knee flexion of the intact limb than the prosthetic limb (Table 2). In contrast, SM demonstrated a NRFS pattern with his prosthetic limb as indicated by an apparent plantarflexed prosthetic ankle at initial contact.

RFS with the intact limb lead to in an early vertical ground reaction peak at approximately 4% of

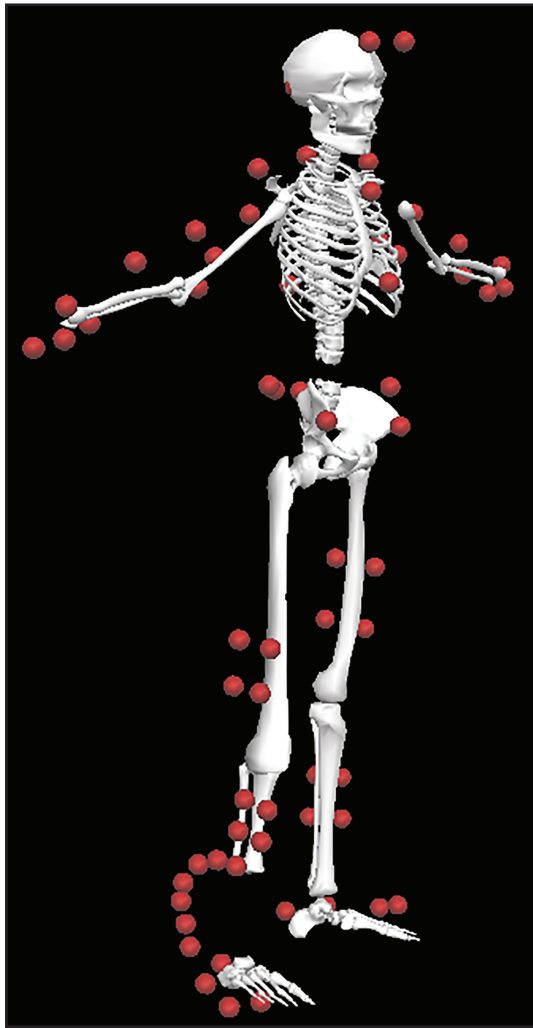


Figure 1. Biomechanical model used to determine kinematics and kinetics. Red circles are the reflective markers placed on body segments shown as bones. The right knee is lower than the contralateral intact knee as the prosthetic knee is below the anatomical end of the distal femur. The pylon that attaches to the prosthetic knee and foot is modeled as a shank to provide knee kinematics. The distal portion of the running foot is modeled as a single segment to provide ankle kinematics relative to the shank. Reflective markers were placed along the entire contour of the prosthetic foot for future analysis related to a multi-axis joint.

the gait cycle (Figure 4). The resulting AVLr in the intact limb was approximately four-times greater than in his prosthetic limb (Figure 5, 112 ± 37 vs. 28 ± 2 body weights/s).

CLINICAL IMPRESSION #2

Temporal-spatial, kinematic, and kinetic asymmetries associated with asymmetric ground-foot striking likely limited SM's running tolerance and efficiency. Further, high AVLrs in the intact limb could potentially lead to repetitive stress injuries if not reduced.⁹ Therefore, an intervention focused on SM learning an intact limb NRFS pattern was developed.

INTERVENTION

A physical therapist (ARD) administered a three-week long running intervention consisting of five, forty-five minute, running sessions (Table 3). Running instruction was conducted on flat outdoor surfaces as well as on a basketball court in a nearby gymnasium. A critical component of the intervention was patient education for the purposes of injury prevention, self-awareness of running errors, and modification of running mechanics. SM was guided through an Army funded running video which focused on injury prevention techniques through the identification of common running errors and instruction on proper running mechanics.²³ Frequent feedback for the purpose of self-awareness was reviewed with SM using a Dartfish video at the conclusion of the running instruction each day to help demonstrate and correct running errors.

Specific running drills and exercises were used to enforce patient education concepts in order to eliminate running errors and modify running technique. Training drills and exercises were performed

Table 1. Self-selected running velocity (m/s), stance times (s), and swing times (s) the intact and prosthetic limbs pre- and post-treatment (Tx). mean \pm sd

Condition - Limb	PreTx - Intact	PreTx - Prosthesis	PostTx - Intact	PostTx - Prosthesis
Velocity	3.066 \pm 0.048	---	3.079 \pm 0.062	---
Stance time	0.257 \pm 0.009	0.220 \pm 0.004	0.220 \pm 0.004	0.220 \pm 0.004
Swing time	0.436 \pm 0.017	0.478 \pm 0.011	0.406 \pm 0.012	0.407 \pm 0.009

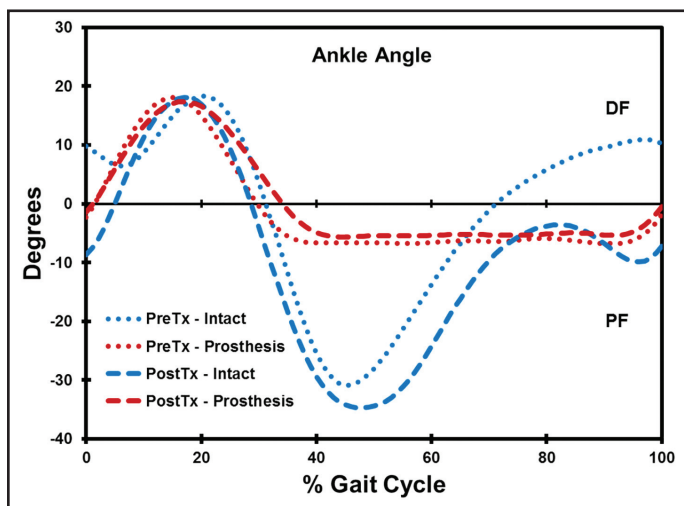


Figure 2. Average intact and prosthetic limb ankle angles through the gait cycle prior to (PreTx) and following (PostTx) the running intervention. Dorsiflexion (DF) is shown in the positive Y-axis and plantarflexion (PF) in the negative.

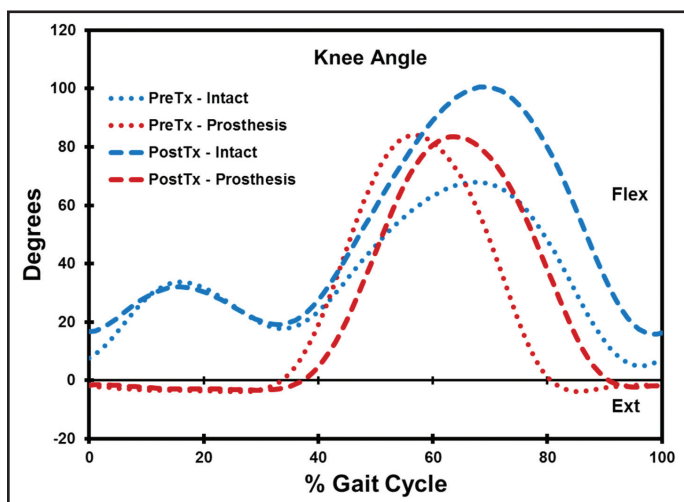


Figure 3. Average intact and prosthetic limb knee angles through the gait cycle prior to (PreTx) and following (PostTx) the running intervention. Knee flexion (Flex) is shown in the positive Y-axis and extension (Ext) in the negative.

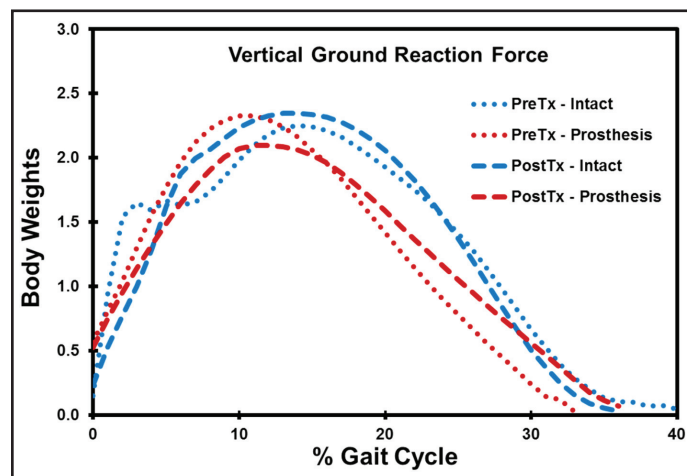


Figure 4. Normalized vertical ground reaction forces in the intact and prosthetic limbs through the gait cycle prior to (PreTx) and following (PostTx) the running intervention. The first peak was used to determine average vertical loading rates.

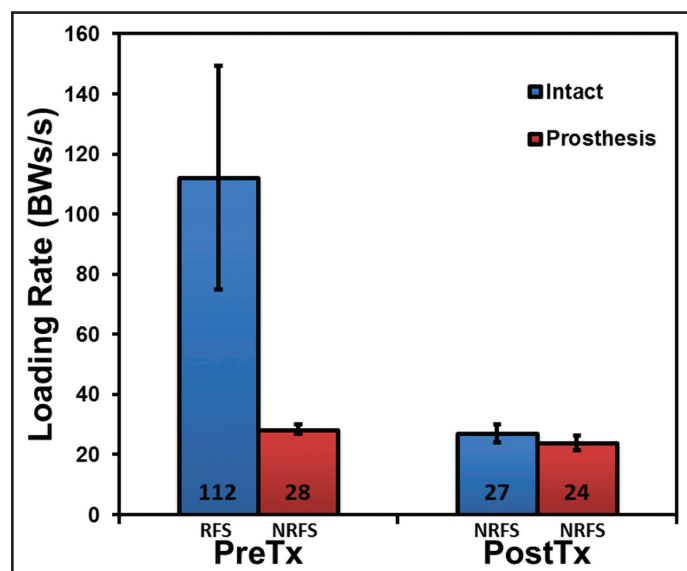


Figure 5. Average vertical loading rates in the intact and prosthetic limbs prior to (PreTx) and following (PostTx) the running intervention. The type of ground-foot striking pattern is indicated as rear foot striking (RFS) or non-rear foot striking (NRFS).

Table 2. Ankle and knee angles (degrees) at initial contact (IC) and peak knee angle during swing (Sw) for the intact and prosthetic limbs pre- and post-treatment (Tx). mean \pm sd

Condition – Limb	PreTx - Intact	PreTx - Prosthesis	PostTx - Intact	PostTx - Prosthesis
Ankle dorsiflexion @ IC	9.8 \pm 1.6	-2.3 \pm 0.8	-8.7 \pm 2.4	-1.5 \pm 1.0
Knee flexion @ IC	7.7 \pm 1.4	-1.9 \pm 0.2	16.7 \pm 2.6	-1.5 \pm 0.8
Peak knee flexion in Sw	68.1 \pm 3.7	84.1 \pm 0.4	100.7 \pm 8.5	83.6 \pm 0.5

Table 3. Five, forty-five-minute running sessions consisted of the following drills and time intervals.

Drill	Description	Volume	Session	Domain
Running Video	Subject watched Pose Running video to introduce the running concept and provide a quick overview	9 minutes	1	Patient Education Visualization of Running Technique
2D Running Assessment (Pre and Post training)	Recorded subjects running form and provided him with an assessment of running errors	3 minutes	1-5	Patient Education Self Awareness of Running Errors
Running in Place	Re-emphasizes the motor pattern of landing on the ball of the foot and pulling the foot from the ground	3 minutes	1	Motor Re-training with Corrective Verbal Feedback
Two Leg Hops	Proprioception drill that also trains pulling the foot from the ground	3 minutes	1	Motor Re-training
Body Weight Shifting/Body Weight Perception	Shifting center of mass onto the forefoot and rearfoot to improve body weight perception through the foot	5 minutes	1	Body Weight Perception
Wall Fall	Practicing falling forward toward a wall with weight on both legs and then on a single leg	10 minutes	1	Dynamic Postural Alignment
Foot Tapping	Subject will pull the foot from the ground directly under the hip utilizing the hamstring musculature	3 minutes	1	Motor Re-training
Skipping	Re-emphasizes landing on the ball of the foot and pulling the foot under the hip while moving forward	5 minutes	1-2	Motor Re-training

Table 3. Five, forty-five-minute running sessions consisted of the following drills and time intervals. (continued)

Front Lunge	Focuses on the pulling the foot from the ground under the hip and recovering the running pose	5 minutes	1-3	Motor Re-training Dynamic Postural Alignment
Cadence Drills	Increasing step rate to at least 180 steps/min by using a digital metronome	Through out session	1-5	Motor Re-training
Prone Hip Flexor Stretch	Increased hip range of motion and improved body alignment when standing	3 x 30 seconds	1-5	Postural Alignment
Prone Press Ups	Improved body alignment when standing and decreased lumbar forward flexion	3 x 30 seconds	1-5	Postural Alignment
Infantry Run	Feedback for pulling the foot from the ground under the hip versus behind the body	5 minutes	1-5	Motor Re-training Postural Awareness
Change of Support/ Change of Support Forward	Incorporating the concepts of unweighing as well as pulling the foot from the ground under the hip and recovering the running pose; progression to forward movement	5 minutes	2-3	Motor Re-training
Running in Place to Forward Running Progression	Re-emphasizes the motor pattern of landing on the ball of the foot and pulling the foot from the ground and progressing to forward movement	5 minutes	2-5	Motor Re-training Postural Alignment
Prone Hip Dips	An unloading drill to assist with running concepts	3 minutes	2, 5	Motor Re-training

Table 3. Five, forty-five-minute running sessions consisted of the following drills and time intervals. (continued)

Prone/Supine	Activating the hamstring	5	4	Motor Re-training
Resistance Pull	musculature to assist with pulling the foot from the ground under the hip	minutes		
Running with elastic bands	Provides feedback to aid with pulling the foot from the ground under the hip during running activity	5 minutes	4	Motor Re-training
Running with the EZ Run Belt	Assistive device to provide feedback to pull the foot from the ground under the hip	10 minutes	4-5	Motor Re-training
Eccentric Hamstring Exercise	Activating the hamstring musculature to assist with pulling the foot from the ground	3 minutes	4-5	Motor Re-training

as described in Table 3 and Figures 6-21, which focused on visualization of running technique, self-awareness of running errors, motor re-training, body weight perception, and dynamic postural alignment. Following each drill a 10-20 meter run was conducted to determine if changes to his running mechanics occurred with that specific drill. At the end of each session the patient was given three drills for his home exercise program. He was initially instructed to perform these three drills at regular intervals of 100 meters during his training runs. As he began to consistently demonstrate a NRFS running pattern he was instructed to increase running distances during his training runs.

OUTCOMES

An identical 3D biomechanical running analysis was performed post-intervention; four weeks following the initial analysis. SM successfully adopted a NRFS pattern in the intact limb as indicated by the

plantarflexed position of his intact ankle at initial contact (Figure 2 and Table 2). His new symmetric ground-foot striking pattern appeared to reduce temporal-spatial, kinematic, and kinetic asymmetries. SM's self-selected running velocity was nearly identical across both running analysis sessions (Table 1). Intact limb stance time was reduced and identical to the prosthetic limb following the running intervention. Likewise, swing times were less than 0.5% different between limbs. AVLRs decreased by 76% and 14% in the intact and prosthetic limbs, respectively (Figures 4-5). The AVLRs were nearly identical with a 13% greater AVR in the intact limb compared to prosthetic limb. The reduction in intact limb AVR was likely associated with NRFS and an increase in intact limb knee flexion at initial contact (Table 2).

With the improvements in running mechanics, SM chose to lengthen his prosthetic limb by 1 cm to allow for additional foot deformation, thus



Figure 6. Running in Place (Reprinted with permission from Pose Method)



Figure 7. Two leg hops (Reprinted with permission from Pose Method)



Figure 8. Body Weight Shifting/Body Weight Perception (Reprinted with permission from Pose Method)



Figure 9. Wall Fall (Reprinted with permission from Pose Method)

increasing energy storage and return. Substantial functional improvements were associated with the observed changes in running mechanics. The SM's two-mile run time on the Army Physical Fitness Test improved from 19:54 mins to 15:14 mins, pre to



Figure 10. *Foot Tapping (Reprinted with permission from Pose Method)*



Figure 11. *Skipping (Reprinted with permission from Pose Method)*



Figure 12. *Front Lunge (Reprinted with permission from Pose Method)*



Figure 13. *Infantry Run (Reprinted with permission from Pose Method)*



Figure 14. *Change of Support (Reprinted with permission from Pose Method)*

post intervention. Pain with running decreased from 6/10 to 0/10, allowing him to compete symptom free in two triathlons within four weeks of the intervention and the Army 10 mile run six months later.

DISCUSSION

SM reported to the physical therapist (ARD) due to an inability to comfortably run distances greater than 5 km even after previous running instruction and training. This limitation restricted his ability to

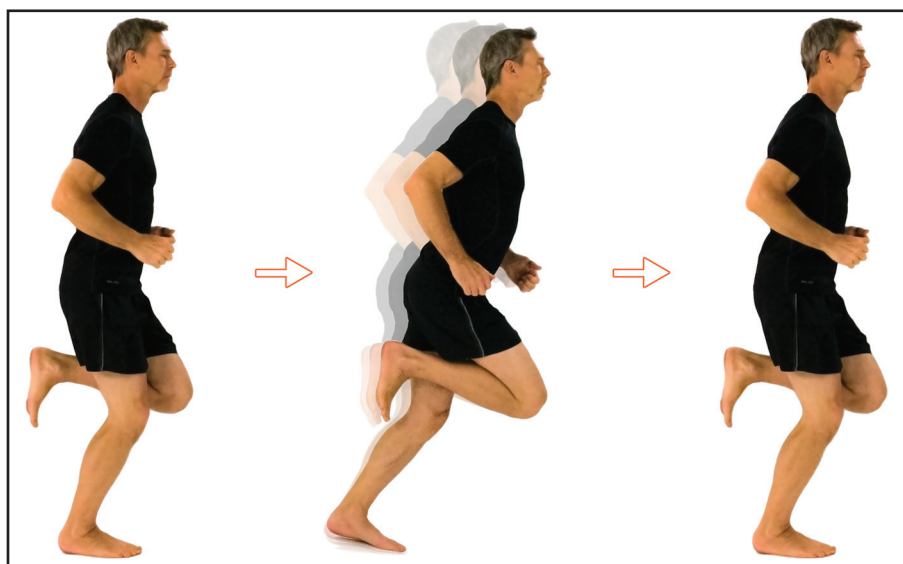


Figure 15. *Running in Place (Reprinted with permission from Pose Method)*



Figure 16. *Prone Hip Dips (Reprinted with permission from Pose Method)*

comfortably compete in desired running events such as triathlons, military runs, and half marathons. 3D biomechanical running analyses revealed temporal-spatial asymmetries between his intact and prosthetic limbs; to include a 300% higher loading rate in the intact limb, which we hypothesized was due to a RFS running pattern. SM participated in five run training sessions over a period of three weeks to learn a NRFS pattern with his intact limb to match

his prosthetic limb. At the conclusion of his training, 3D biomechanical running analyses revealed a successful adoption of a NRFS pattern which decreased the intact limb loading rate and temporal-spatial asymmetries. SM was also successful in competing in several running events; completing distances up to 10 miles.

Increased loading rates are known to cause a greater number of running related musculoskeletal injuries in non-amputees; often related to a RFS running pattern. Individuals with limb loss who run with a RFS on the intact limb may also be susceptible to similar musculoskeletal injuries. Further, increased loading rates resulting from a RFS pattern may worsen conditions that amputees are predisposed for, such as skin breakdown, residual limb swelling, and an inability to tolerate higher level activities due to pain.²⁴ In order to lessen the risk for certain types of musculoskeletal injuries during running implementation, rehabilitation programs should consider instruction to foster NRFS running patterns and decreased limb loading rates. Pre-intervention, SM's intact limb AVLR was 300% greater than the prosthetic limb and above a 70 BW/s threshold reported to increase risk for tibial and metatarsal stress fractures, patellofemoral pain syndrome, and plantar fasciitis.^{9,14,20} Following our three week running intervention, intact limb AVLR decreased to 27 BW/s; which was a 315% decrease from pre-intervention values. Similar decreases in limb loading rate, following a four week

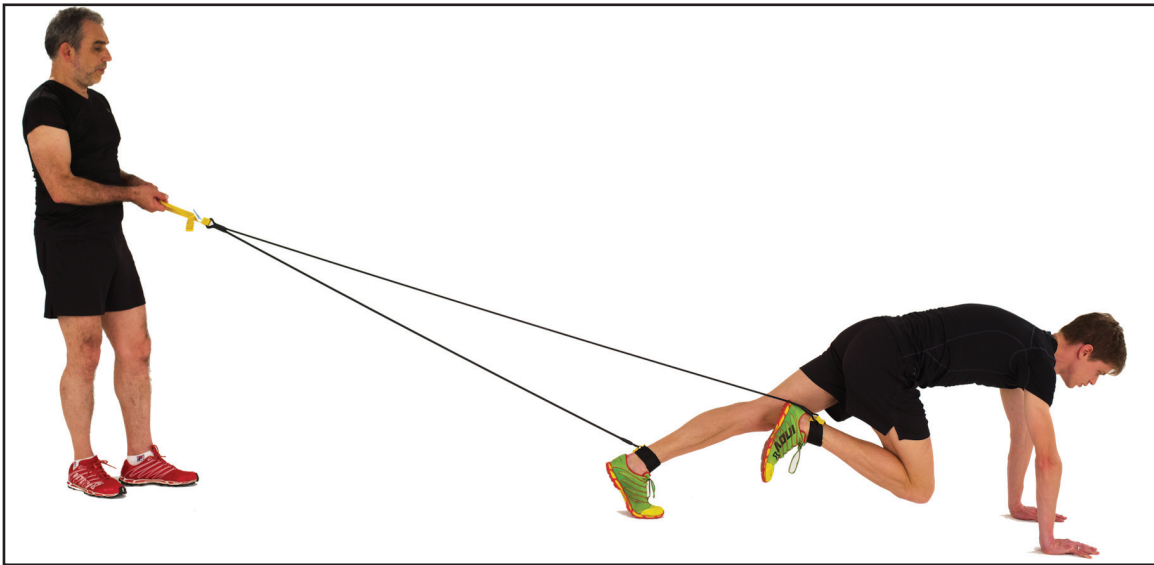


Figure 17. *Prone Resistance Pull (Reprinted with permission from Pose Method)*

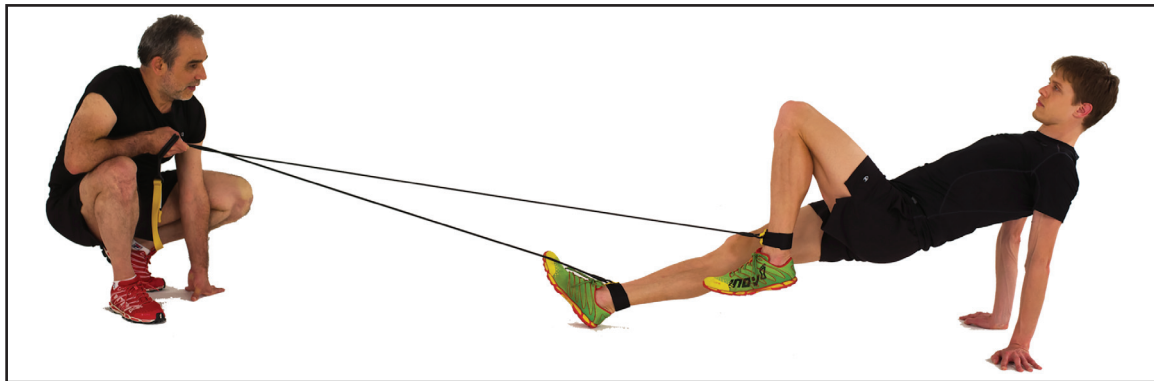


Figure 18. *Supine Resistance Pull (Reprinted with permission from Pose Method)*

NRFS running intervention, were reported in an individual with a unilateral transtibial amputation.²¹

Despite SM's running instruction prior to the intervention described in this case report, he was unable to comfortably tolerate running distances greater than 5 km. He participated in distances up to 10 miles but he experienced significant pain and discomfort, which required several down days to recover. Even though SM was able to complete distances up to 10 miles, he did so with poor running mechanics and without the understanding of how to properly train for these long distance running events. Essentially he faced common roadblocks that many able-bodied runners encounter. History of previous injury, high weekly running mileage/volume, and increased impact force,^{7,25,26} can all contribute significantly to

musculoskeletal running injuries. In addition, learning to run with a prosthesis may be more challenging and result in poor running mechanics; and when left uncorrected may increase the risk for musculoskeletal injury. Individuals with unilateral limb loss are five to 10 times more likely to suffer secondary musculoskeletal changes in their intact limb compared to those without limb loss.²⁷⁻³⁰ Thus, compared to able-bodied runners, an individual with limb loss may be at greater risk for musculoskeletal injuries when increasing mileage with uncorrected running mechanics.

Correcting poor running mechanics prior to increasing mileage is essential to preventing injuries. In this regard, a training program for able-bodied individuals and individuals with amputation are



Figure 19. Running with Elastic Bands (Reprinted with permission from Pose Method)



Figure 20. Running with the EZ Run Belt (Reprinted with permission from Pose Method)



Figure 21. Eccentric Hamstring (Reprinted with permission from Pose Method)

comparable. The program should consist of multi-axial, neuromuscular, and proprioceptive activities to decrease injury risk, evenly distribute musculoskeletal stresses, and improve running economy.^{31,32} Additionally, a runner's cadence should be increased to 180 steps/min or more so the foot strikes directly under the runner, thereby eliminating the RFS. Increased cadence and a NRFS ground contact style

will decrease the magnitude of loading throughout the lower extremity and together are crucial to mitigating common running injuries.^{33,34}

Depending on the type of running prosthesis used, kinematic running patterns may become asymmetric and/or deviate from proper running form. SM utilized an articulating prosthetic knee (3S80) which

demonstrated kinematics similar to the intact knee (Figure 3). Following the intervention, the prosthetic knee kinematics did not appear to change but the intact knee flexion during flight improved with the change to an NRFS pattern. Some amputee runners utilize non-articulating knees or no knee at all (i.e. straight pylon attached to running foot). A non-articulating knee can cause a hip circumduction of the prosthetic limb in order to clear the prosthetic foot during flight. The decision to utilize an articulating versus a non-articulating knee is often a decision made between the prosthetist, therapist, and the patient. Considerations to ponder when choosing an articulating or non-articulating knee are energy costs and running mechanics. In the study conducted by Highsmith et al,³³ energy costs, rate of perceived exertion, and heart rate was reduced and faster maximal speed was reached with an articulating knee versus a non-articulating knee. Energy costs for individuals with a transfemoral amputation are significantly greater than non-amputees. It is, therefore, imperative to incorporate prosthetic devices that decrease energy costs and improve ambulatory performance; especially in high functioning athletes. After discussions, which included literature review and sharing of clinical experience, SM chose to run with an articulating knee. Since the intervention, he has been able to successfully utilize his articulating running prosthesis for distances up to 13 miles without detriment. Six months following intervention, he placed third in a 10-mile run and completed one half marathon, both without pain. Presently, he is in the World Class Athlete Program training for a triathlon in the next Paralympics.

CONCLUSION

Currently, limited knowledge exists regarding specific training protocols for returning individuals with lower extremity limb loss to run. Additionally, it is not known whether these individuals require additional recovery time for tissue healing to prevent skin breakdown and other complications. This case report outlines a detailed return to run program, which addresses numerous proprioceptive and neuromuscular factors, targets injury prevention, and follows specificity of training strategies. Further study is warranted since the findings of this case report cannot be generalized to a larger population. The

outcomes of this case report are promising as they may spur additional research toward understanding how to eliminate potential injury risk factors associated with running following limb loss. The training regimen described in this case study will hopefully allow individuals with limb loss to improve their quality of life through a return to running sports.

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